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A NEW HIGH-SPEED SOLAR RADIO SPECTROGRAPH FOR METER AND DECAMETER WAVELENTHS

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A NEW HIGH-SPEED SOLAR RADIO SPECTROGRAPH

FOR METER AND DECAMETER WAVELENGTHS

Stephen R. Mosier
Joseph Fainberg

CONTENTS

1. INTRODUCTION

Since the first sweep-frequency solar spectrograph was described by Wild and McCready [1950], there has been a steady effort to obtain spectrograms of increased resolution at decimeter through decameter wavelengths. The efforts have advanced by two methods: the sweep-frequency (SF) receiver, in which the frequency band under observation is scanned over and over again with a single channel, and the multi-channel (MC) receiver, in which radiation is received simultaneously in several channels which are closely spaced in frequency. The frequency and temporal resolution of SF spectrographs remained at the order of several hundred kilohertz and several hundred milliseconds, respectively, over the frequency range from 25 to 500 MHz through the 1950's. In an effort to obtain improved resolution for the study of type I noise storms, which were largely unresolved by existing SF spectrographs, Elgarøy [1959] built a two-channel receiver at 200 MHz. An eight-channel receiver was also put into operation at 390 MHz by de Groot [1959]. MC spectrographs achieve high sensitivity and permit relatively simple display of data on strip-chart pen recorders, but it is often difficult to construct accurate dynamic spectra from the records since the bandwidth of each channel is usually much less than the spacing between adjacent channels and bursts may have bandwidths comparable to, or less than, the channel spacing. Development of SF spectrographs therefore continued and Elgarøy[1965] built an instrument for the range 195 to 220 MHz with a 300-MHz bandwidth and 20-millisecond sweep period. Comparable resolution at decameter wavelengths was not realized until the mid- to late-1960's. Ellis and McCulloch [1967] constructed an SF spectrograph of similar resolution, using four separate SF receivers in the ranges 24 to 28, 28 to 36, 36 to 46, and 46 to 60 MHz with bandwidths of 30, 30, 30, and 50 kHz, respectively. The sweep period of each receiver was 20 milliseconds. Warwick and Dulk [1969] developed an SF spectrographic polarimeter with 60-kHz bandwidth and 10-millisecond sweep period in the 24 to 37 MHz range. The actual time resolution for linear polarization was 20 milliseconds since linear and circular polarization modes were multiplexed on alternate sweeps. More recently, Gotwols and Phipps [1972] constructed a spectrograph which scans the range from 565 to 1000 MHz with a 10-millisecond sweep and

2.4-MHz bandwidth. Even with increased resolution, however, the SF receiver suffers from the fact that the fraction of the observing time which is spent at any one frequency is small, thereby reducing sensitivity. Thus, as solar burst measurements of higher sensitivity were sought, MC spectrographs continued to be utilized. Sastry [1971] operated a three-channel receiver at 25 MHz having 100-kHz channel separations, 6.5-kHz bandwidth, and 15-millisecond time resolution. De Groot [1970] constructed a 160- to 320-MHz, 60-channel spectrograph with 2.6-MHz channel separation, 900-kHz bandwidth, and 10-millisecond time resolution.

In any spectrograph design there are three basic parameters which one attempts to optimize but which must be compromised in favor of each other: frequency resolution, time resolution, and sensitivity. As noted above, sensitivity always presents a problem in SF spectrograph design, with MC spectrographs offering a multiplicative increase in sensitivity by the number of channels used. An even greater problem, however, concerns itself with dynamic range and data handling procedures. As higher instrumental resolutions are achieved, the quantity of data record output necessary to display the increased resolution grows until data handling becomes a major problem. The pen and ink records often used for MC spectrograph output represent large weights and volumes in storage; the film used for the display of frequency-time spectra, although more compact, severely limits the dynamic range, usually to between 20 and 30 db, far below that achievable with present spectrographic receivers. In addition, both data display methods suffer from the fact that extensive analyses of analog data formats are time-consuming, requiring either hand calculations or lengthly conversion to digital form for use by computer. Thus, even though high-resolution spectrography has been achieved, the data handling methods have not kept pace to the point that regular routine observations are practical.

It was with the above considerations in mind that a new high-resolution digital solar spectrograph was designed for operation at the Clark Lake Radio Observatory in southern California in the 10- to 80-MHz range. This frequency range is of particular interest since it covers the transition region from meter-wavelength to decameter-wavelength phenomena, a range marked by significant changes in the spectral characteristics of solar bursts. The primary considerations in the design of the new spectrograph were (1) optimum sensitivity, (2) wide dynamic range, (3) flexibility in time and frequency resolution which would serve a variety of research interests, and (4) modern data-handling techniques with simple computer interface. The spectrograph was developed in three stages: the receiver, the control and data acquisition systems, and the computer software systems. The spectrograph is described in detail in the following sections.

2. SPECTROGRAPH SYSTEM DESCRIPTION

2.1 Hardware Subsystem

2.1.1 General

A block diagram of the new Clark Lake spectrograph is shown in Figure 1. The output from a wideband receiver goes to a 16-to-1 power splitter. Each of the power splitter outputs then goes to a crystal filter and a logarithmic amplifier and detector, yielding 16 separate output channels, spaced 100 kHz apart with 20-kHz bandwidths. These 16 outputs are then fed to a signal conditioner, analog multiplexer, and analog- to-digital converter. Calibration of the spectrograph is accomplished by attenuating the output of a high-power noise source in discrete steps. The calibrator is driven by the system programmer, which also feeds calibrate level information to a digital multiplexer during the calibration cycle. The receiver operating frequency can be set either by an array of fixed-frequency oscillators or by a programmable frequency synthesizer operating as the first local oscillator. The synthesizer is also controlled by the system programmer, which feeds frequency data to the digital multiplexer. The digital multiplexer also accepts clock data. Both multiplexers have auxillary inputs with signal conditioning available for future requirements. The multiplexer outputs are fed to the system programmer which in turn controls the multiplexers and tape drive for proper data formats. The system programmer also formats the antenna switches, one of which is used to switch the calibrator into the spectrograph system and the other to multiplex signals from two separate antennas. Synchronization of the system programmer is obtained from the digital clock. The individual subsystems of the spectrograph are described in the following sections.

2.1.2 Multi-Channel Receiver

The basic design goal of the receiver was to provide a stable dynamic range of 60 db over a frequency range of 10 to 80 MHz with capability of high speed frequency switching. The design utilized existing off-the-shelf modules (amplifiers, balanced mixers, filters, oscillators, etc) with external connectors to insure ease of repair and reconfiguration. A double frequency conversion was planned in order to eliminate problems with images and spurious responses over the wide frequency range.

The first frequency conversion is an up conversion to 90 MHz followed by a sharp skirted filter which limits the bandwidth to 4 MHz. The second conversion is down to 30 MHz followed again by an external bandpass filter. The 30 MHz IF (4 MHz bandwidth) is split into 16 separate channels at 100 kHz frequency intervals. Each channel consists of a crystal filter (20 kHz bandwidth) followed by a 30 MHz logarithmic amplifier feeding a detector.

All filters provide out of band rejection in excess of 80 db. Low intermodulation amplifiers are used throughout the system and are operated at low quiescent signal levels to provide an operating range in excess of 60 db. The entire system is composed of solid state electronics and utilizes temperature compensated crystal oscillators. This results in a very stable amplitude and frequency operation over the entire range of the receiver. A typical channel response is shown in figure 2.

2.1.3 Signal Conditioners and Multiplexers

Two types of data are handled by the spectrograph system: analog data in the form of voltages from the receiver detector outputs, and digital data generated by the system programmer and system clock which is necessary to annotate the analog data with time, frequency, signal source, and data format status. Since the magnetic tape drive requires a steady stream of formatted data, the various analog and digital data must be combined before writing on the tape. This is accomplished in a two-step process: first, the analog and digital data are multiplexed separately, and then the two multiplexed data streams are combined by the system programmer in the proper format. Auxillary inputs are provided to both multiplexers for additional data as might be desired in the future.

Each of the detected 16 channels of analog data from the multichannel receiver are applied to each of two integrated circuit operational amplifiers which exhibit either a gain of four or a gain of one, as determined by a switch in the amplifier feedback circuit. The gain-of-four setting corresponds to a 0.510-volt full-scale input and the gain-of-one to a 2.040-volt full-scale input. The output of each operational amplifier is applied to an RC integrating circuit which may be selected to provide 10- or 20-millisecond RC time constants, corresponding to 20- and 40-millisecond equivalent pure integration time constants. Longer integration times can be obtained using plug-in multipliers. In normal operation, one amplifier in each output channel is set at a gain of four and the other amplifier at a gain of one. The gain-of-four amplifiers are then scanned separately from the gain-of-one amplifiers by the analog multiplexer, providing two separate range scales in the receiver output data of approximately 20 db and 75 db dynamic range. The multiplexed analog data is then buffered and applied to the analog-to-digital converter, the output of which can then be accessed by the system programmer. The A-to-D converter provides 8-bit resolution, corresponding to resolutions of .07 db and .26 db in low-range and high-range, respectively.

A large number of digital data are generated by the system in order to annotate system operation. These data identify frequency, time, and calibration status, as well as various programmer format modes, and are applied to the digital multiplexer by the system programmer and system clock. The multiplexed bit stream can then be accessed by the system programmer.

2.1.4 Calibrator

The spectrograph system performs an antenna temperature calibration every 30 or 60 minutes, as determined by the programmer setting. In addition, an operator may initiate the calibration sequence at any time and/or reset the timing cycle without disturbing system operation. The calibration consists of 32 discrete noise temperature steps applied to the receiver input. The first 11 calibration steps range from 3.2×10^{11} K to 3.2×10^{6} K in 5-db steps, and the last 21 steps range from 10^{6} K to 10^{4} K in 1-db steps. The duration of each step can range from 300 to 600 milliseconds and is controlled by the system programmer. Thus, a complete calibration sequence requires from 9.6 to 19.2 seconds, depending upon step duration. The noise source consists of two 20-db gain, wideband integrated amplifiers connected in series, followed by variable trim-attenuators and a programmable attenuator with a 75-db range in 1-db steps. The input to the programmable attenuator is maintained at 75 db above 10^4 K by balancing with trim attenuators against a calibrated 10^4 K source. The noise source temperature stability has been measured over both long and short periods and is extremely stable, within a few tenths of a db. The calibration step accuracy is a function of the programmable attenuator accuracy and the flatness of the noise source, and is approximately 0.2 db.

2.1.5 <u>System Programmer</u>

2.1.5.1 General

Illustrated in Figure 3 is a block diagram of the system programmer. It consists of four basic sections: the data format controller, the calibrator controller, the antenna controller, and the synthesizer controller. The data format controller is the heart of the system, since all peripheral control must be synchronized to the basic data format.

2.1.5.2 Data Format

The basic data format is diagrammed in Figure 4. Data is blocked into individual records of some constant character length, each record being separated from the adjacent record on the tape by an inter-record gap (IRG). Each record consists of time data and operational mode data followed by repetitive scans of annotated receiver data. A byte (8-bit word plus parity bit) is written on the tape once every millisecond. When the preset record length has been reached (maximum of 32000 bytes) the IRG is generated and a new record begins. The time of the first byte, to the nearest one millisecond, together with various operational mode parameters, is written on the first 15 bytes of each record. Some of these data are provided automatically by the system; other data must be entered manually at the system front panel prior to a data run. Repetitive scans of digitized receiver data are then initiated on the sixteenth byte. The time associated with each byte is accurately known by counting from the first byte on the record, for which time was recorded. Each repetitive scan consists of one antenna identification word (byte), 16 low-range receiver channel words, 16 high-range receiver channel words, up to seven auxillary channel words, one calibrate status word, and two words which identify the receiver frequency to 10 kHz, for a 43-word (43 millisecond) maximum scan. The scan length may be decreased to omit analog samples from the auxillary channels down through high-range channels to low-range channels. Calibration and frequency status are always written at the end of the analog input channel scans. In normal operation to date, the auxillary channels are deleted, giving a 36-byte (36-millisecond) scan. These scans continue until the record is filled.

2.1.5.3 Data Format Controller

The data format controller has central control over the entire spectrograph system. The basic control input is the 1000 pulse-per-second clock line and a number of front-panel switch settings which determine the record and channel-scan lengths. System control is passed to the multiplexers and tape drive and control pulses are provided to the calibrator, antenna, and synthesizer controllers, which are essentially sequential stepping devices. Two basic control pulses are generated in the data format controller: the block pulse, which is coincident with the writing of the first byte in a data record, and the scan pulse, which is coincident with the first sample in a repetitive analog channel scan sequence. The remainder of the system controller is synchronized to these two pulses.

2.1.5.4 Calibrator Controller

The calibrator controller is synchronized to three inputs: one pulse-per-minute (PPM) from the clock, and the scan and block pulses from the data format controller. The 1 PPM is divided by 30 or 60 to set the calibration cycle. When the cycle time has been counted, the controller is "armed" and waits for the next block pulse. After the block pulse is received, the first scan pulse starts the calibration sequence. Thus, the calibration always begins in the first analog channel scan in a data record. The scan pulse is divided by one to fifteen to determine the calibration step duration. The output of the scan pulse divider is applied to a read-only-memory (ROM) which formats seven BCD lines to the programmable attenuator in the calibrator. The ROM format is fixed at the 32 calibration sequence steps. The calibrator controller also provides an output to the antenna controller for switching the calibrator into the receiver input at the proper time and a set of calibration status output lines to the digital multiplexer.

2.1.5.5 Antenna Controller

The antenna controller operates in two modes: one in which a single antenna is sampled by the receiver, and another in which the receiver is switched between two antennas on alternate receiver scans. In both modes, the antenna controller also switches the receiver to the calibrator upon instruction from the calibrator controller. Input to the controller is the scan pulse, and output is to the antenna switching devices, as well as an antenna indicator voltage to the analog multiplexer, which is written as the first sample in each receiver channel scan sequence.

2.1.5.6 Synthesizer Controller

The synthesizer controller is driven by the scan pulse from the data format controller and, after division to determine the sequencing rate, sequentially steps through from two to fifteen sets of frequency control lines which have been set into the front panel controls. These frequencies are determined down to the 10-kHz digit and each frequency can be set anywhere within the range of the instrument. It is at this point in the system that a spectrum can be synthesized and that the basic tradeoff between frequency resolution and time resolution occurs: the time between samples at one given frequency is proportional to the number of frequencies being sampled. There are a number of options available for setting up a frequency switching sequence. The synthesizer frequencies can differ by less than the 100-kHz receiver channel spacing, in which case the frequency resolution can be increased to the point of actual channel overlap, or the frequencies can be widely separated to provide either continuous 100-kHz channel spacing over an extended frequency range or to provide short segments of 100-kHz channel spacings, each group being widely separated. In addition, any combination of these might be employed to provide fine resolution at one frequency and coarse resolution at another. This frequency switching, together with the capability of limiting the length of the receiver channel scan, provides extreme versatility in the spectrograph format. The synthesizer controller provides a set of output lines to the digital multiplexer which identify the local oscillator frequency in use during each channel scan.

2.1.6 Tape Drive

The tape drive is a 9-track incremental stepping recorder, IBM-360 compatible, writing 1000 characters per second at 800 bits per inch. IRG generation time is 60 milliseconds.

2.2 Software Subsystem

2.2.1 General

The software subsystem for the Clark Lake Solar Spectrograph consists of two programs, run separately: the interactive analysis segment, utilizing the IBM 2250 CRT graphics display unit, and the plotting segment, which produces three data plot formats for each of three different plotting devices plus printer plots. All programs are run on the NASA/GSFC IBM 360-91 computer.

2.2.2 Interactive Analysis Segment

The interactive analysis segment is used for preliminary analysis of the solar data. The data analyst observes the data on the 2250 CRT unit and decides at that point if the data is worthy of analysis. The user then has available a number of analytical tools which he can call for, including the computation of burst drift rates, peak time, rise and decay time at 1/e, -3 db and -10 db, peak intensity, background intensity, background standard deviation, and a burst curve fitting analysis.

The data flow for the interactive analysis segment is diagrammed in Figure 5. Input is received from the data tape and data cards which describe the data sets and I/O devices required. Before display, calibration records are located on the data tape and piecewise cubic curves are fitted through the calibration points in each channel on each amplitude range and for each receiver frequency and each antenna. This piecewise cubic function is the mathematical analog of the draftman's spline and represents the smoothest curve which can pass through each data point [Thompson, 1970]. The user may then interact with the data display using a light pen to identify features on the screen, a typewriter keyboard to define parameters, and a set of 30 function keys to initiate program operations. A typical screen display is shown in Figure 6. In this display, the Block Start time, the time of the first byte in the data record, is given at the bottom as year.month.day.hour.minute.second.millisecond, together with the number of the displayed record (Block No.), counting from the beginning of the data file. The times along the absicissa are then a continuation of the seconds given in the Block Start time. Frequency is displayed on the oblique axis and antenna temperature on the ordinate, with E5 corresponding to 10^5K, E6 to 10^6K, etc. The curve frequencies listed at the top of the display are those channels and corresponding frequencies which have been selected. Available program operations, in addition to the burst analysis features described above, include the expansion or compression of the time and intensity scales, the omission or addition of any receiver channels, spanning ahead to another time period, and the generation of two output tapes. The first, the SNAPG tape, is a microfilm plotter tape of the CRT screen, of which Figure 6 is an example. The second, the COMPACT tape, is a copy of the particular record from the data tape at twice the density, 1600 BPI. Thus, the COMPACT tape is a library tape of all interesting data encountered in the CRT analysis. The original data tape is normally not processed again. The interactive analysis segment will accept either the 800 BPI data tape or the 1600 BPI library tape as input without prior specification. As additional output, a card index is generated for each entry on the COMPACT tape. These cards can then be ordered chronologically for a master library index. A printer run report is also produced, listing each operation performed as well as the results of the various analytical operations initiated by the function keys, light pen, and typewriter keyboard.

Referring to Figure 6, the number of data points which may be displayed on the CRT screen is limited by the size of the display unit buffer. In practice, only about five channels may be displayed with accuracy at any one time, but even at this number the system will only plot every third or fourth data point. However, such a display is sufficient for burst identification and preliminary analysis. When an analysis routine is called for, the computer utilizes the complete data array, even though all points are not displayed on the CRT screen. Approximately 300K bytes of core are required for running the interactive analysis segment.

2.2.3 Plotting Segment

Illustrated in Figure 7 is a data flow diagram for the plotting segment of the software subsystem. There are three inputs to the program: the data tape (either the original 800 BPI data tape or the 1600 BPI library tape), a set of instruction cards describing the data sets to be processed, and a set of NAMELIST parameters which describe the desired plotting methods and formats. Data calibration is performed in the same manner as for the interactive analysis segment. There are four output forms: a printer plot utilizing alphanumeric characters on a standard line printer, as well as plot tapes for the Calcomp drum plotter, Gerber flatbed plotter, and the Stromberg-Carlson 4020 microfilm plotter. Any or all of these plot devices may be called for in a single program run. In addition, the user may select any or all of three standard plot formats. These formats are illustrated in Figures 8, 9, and 10 for the same data record shown in the CRT display of Figure 6. Figure 8 is similar to Figure 6 except that all channels and all data points are displayed. Coordinate identification is the same. Figure 9 is the same plot except that the oblique frequency axis has now been eliminated and the different channels plotted directly above each other, facilitating time comparisons between channels. Illustrated in Figure 10 is an isophote contour plot, in which contours of constant antenna temperature are plotted for the same data set as in Figures 8 and 9. The contour interval is listed in db, with frequency on the ordinate and time on the abscissa as before. As in the CRT display, the user may specify, via the NAMELIST input cards, scale lengths and data selection for each plot format, as well as the contour interval, contour limits, and data smoothing parameters for the contour format.

3. INITIAL OBSERVATIONS AND RESULTS

Observations utilizing the new Clark Lake solar spectrograph are being conducted from 1800 to 2045 UT each day. During 1972 and 1973 a single log-periodic antennas was utilized. Beginning in November 1973 right- and left-handed circularly polarized antennas are multiplexed.

The most striking feature of the data analyzed to date is the occurrence of narrow-band structure in most type III bursts. To review briefly, the type III burst is characterized by a rapid drift with time toward lower frequencies and is generally thought to be excited by the outward motion, through the solar atmosphere, of a localized particle stream which excites plasma oscillations of continually decreasing frequencies. These plasma oscillations can then be coupled to an electromagnetic wave mode and propagate into the interplanetary medium. The narrow-band structure which is observed in the type III bursts often has the form of a superimposed burst of low intensity and very short duration, generally of the order of a second at decameter wavelengths, whereas a normal type III burst usually lasts for tens of seconds. Such narrow-band bursts may occur either before or after the peak of a main type III burst, but are also observed to occur as isolated events, independent of other bursts. De la Noë and Boischot [1972] reported the occurrence of narrow-banded bursts which have a strong tendency to appear in chains and which drift in frequency in a manner similar to the type III bursts. These authors termed the burst type IIIb and considered it to often be a precursor of a normal type III burst. The narrow-band bursts observed at Clark Lake generally have the same characteristics as the type IIIb bursts identified by de la Noë and Boischot but are not confined to a precursor relationship. Figure 8 illustrates such a burst observed on 20 October 1971 in which a short-duration, narrow-band burst of low intensity occurs after a normal type III burst has decayed almost to background. At a frequency of 40.35 MHz, the burst has a duration of two seconds and an intensity of about 3 to 4 db, but at 40.45 MHz, only 100 kHz higher, the burst is not observed at all. In Figure 10, where the same event is plotted in the contour format, the narrow bandwidth of the burst is emphasized.

The burst intensities which are observed in the high-speed data vary dramatically as a function of frequency, and hence altitude, in the solar atmosphere. This might be due to variations in the emission conditions or variations in the propagation conditions. However, it seems doubtful that a propagation mechanism, operating at any appreciable distance from the source, could account for the very narrow-band structure, due to simple broadening of the propagating beam. There would be a problem of coherence. On the other hand, plasma conditions which might affect the beam propagation close to the source would probably control the emission mechanism as well and so it seems likely that the narrow-band structure reflects variations in the emission conditions along the path of the ejected particle stream.

Several observations of decametric continuum events have been performed in the frequency range of 35 to 65 MHz. No correlated structure has yet been observed between adjacent channels (100 kHz spacing) at time resolutions down to 36 milliseconds.

4. FUTURE PLANS

Initial observations of solar bursts using the Clark Lake Spectrograph have suggested many interesting areas of future analysis. Although the complete hardware subsystem was first put into operation in October 1971, the software subsystems were not completed until summer of 1972 and thus extensive analyses of the data have only recently begun. The first priority in future analysis is the detailed definition of the characteristics of narrow-band burst structure. To aid in this task, burst observations have begun utilizing two antennas of opposite circular polarizations. In addition, the comparisons of the digital spectrograph records with data from the grating interferometers at Clark Lake will provide information on the relative positions of the type III and type IIIb bursts which occur together. Observations of decametric continuum events at time resolutions down to 20 milliseconds have begun and will continue.

ACKNOWLEDGEMENTS

The authors wish to express their thanks to Mr. George Welch for this considerable effort in the design of the soft-ware subsystems.

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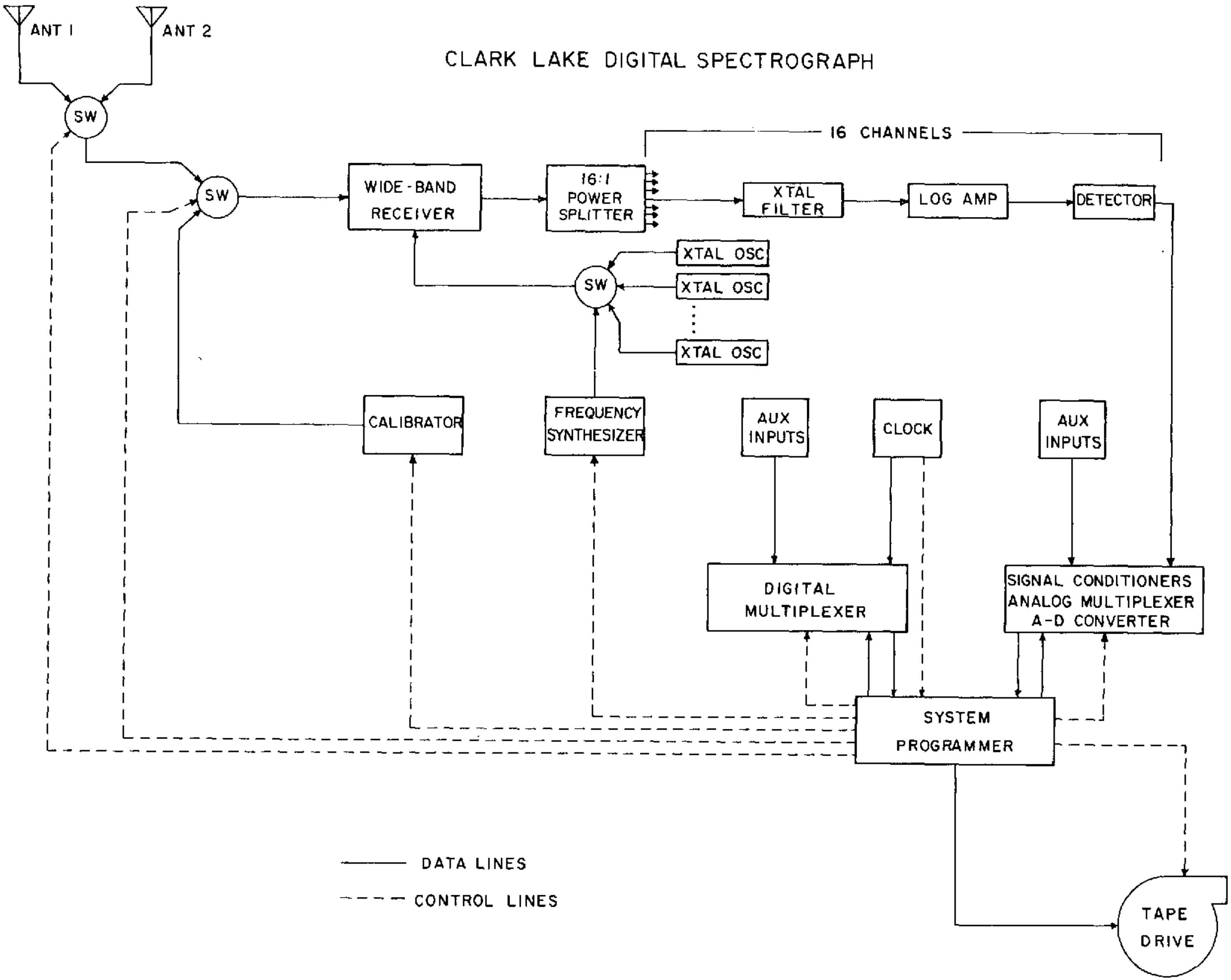
FIGURE CAPTIONS



CLARK LAKE DIGITAL SPECTROGRAPH
ANT 1
ANT 2
SW
SW
16 CHANNELS
WIDE-BAND RECEIVER
16:1 POWER SPLITTER
XTAL FILTER
LOG AMP
DETECTOR
XTAL OSC
XTAL OSC
XTAL OSC
SW
CALIBRATOR
FREQUENCY SYNTHESIZER
AUX INPUTS
CLOCK
AUX INPUTS
DIGITAL MULTIPLEXER
SIGNAL CONDITIONERS
ANALOG MULTIPLEXER
A-D CONVERTER
SYSTEM PROGRAMMER
TAPE DRIVE
DATA LINES
CONTROL LINES

Figure 1

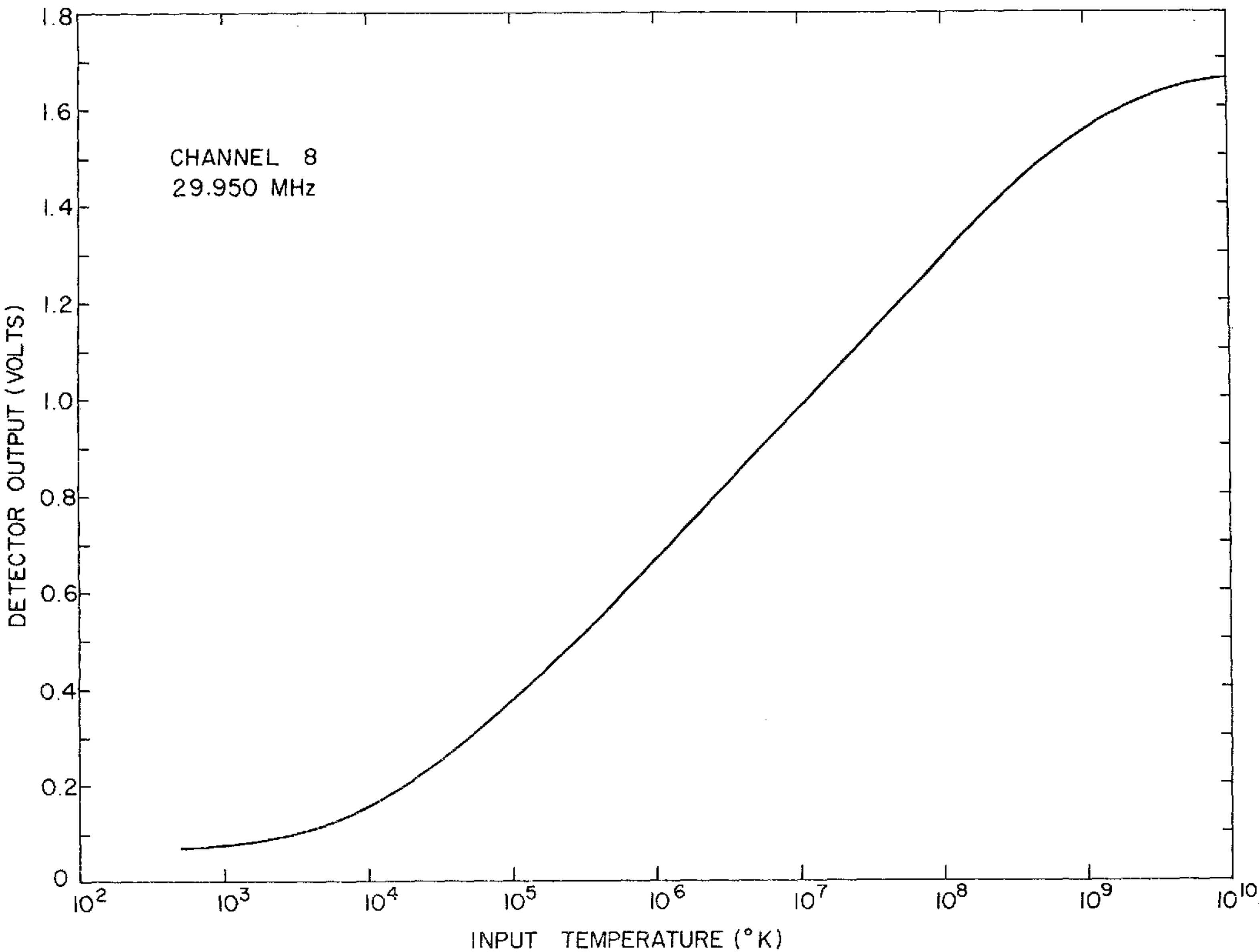

CHANNEL 8
29.950 MHz
DETECTOR OUTPUT (VOLTS)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^{10}
INPUT TEMPERATURE (°K)

Figure 2

SPECTROGRAPH SYSTEM PROGRAMMER

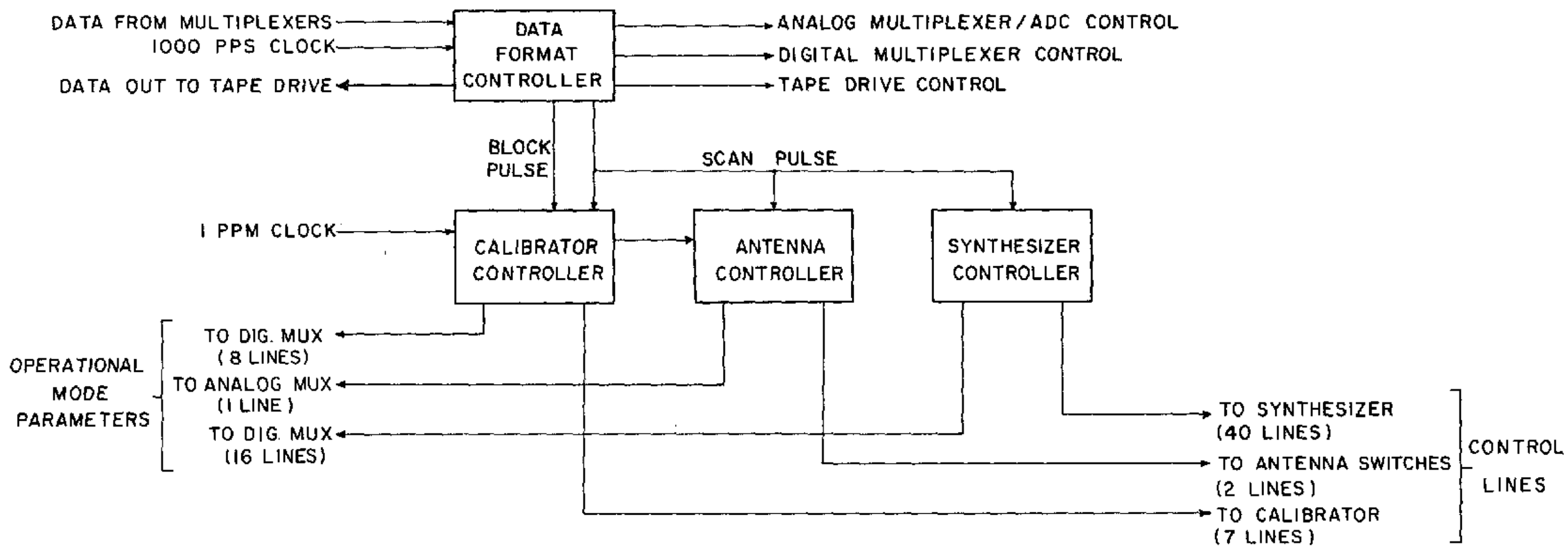


Figure 3

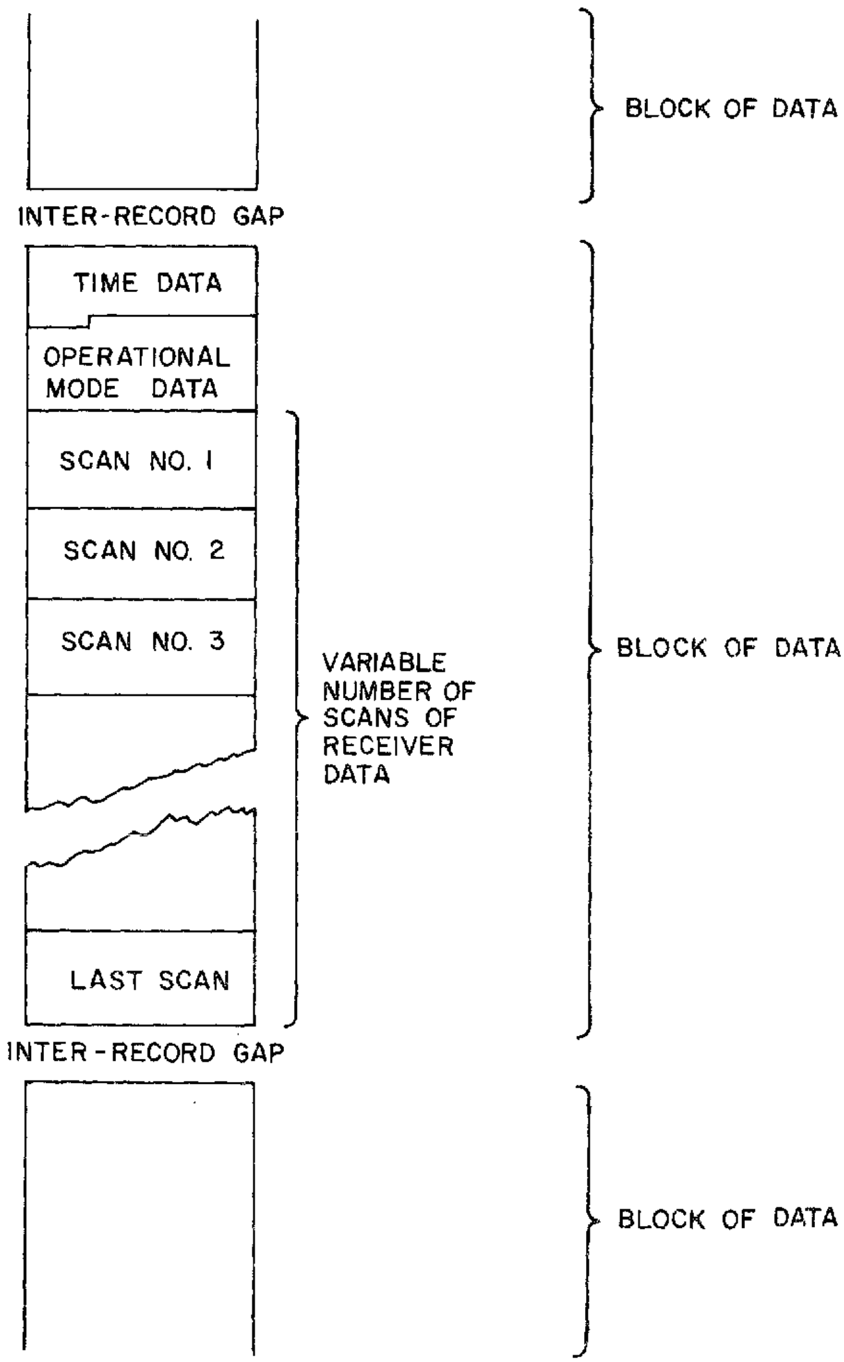

BLOCK OF DATA
INTER-RECORD GAP
TIME DATA
OPERATIONAL MODE DATA
SCAN NO. 1
SCAN NO. 2
SCAN NO. 3
VARIABLE NUMBER OF SCANS OF RECEIVER DATA
BLOCK OF DATA
LAST SCAN
INTER-RECORD GAP
BLOCK OF DATA

Figure 4

INPUT TAPE SERIAL NUMBER
AND FILE. COMPACT TAPE
SERIAL NUMBER AND FILE

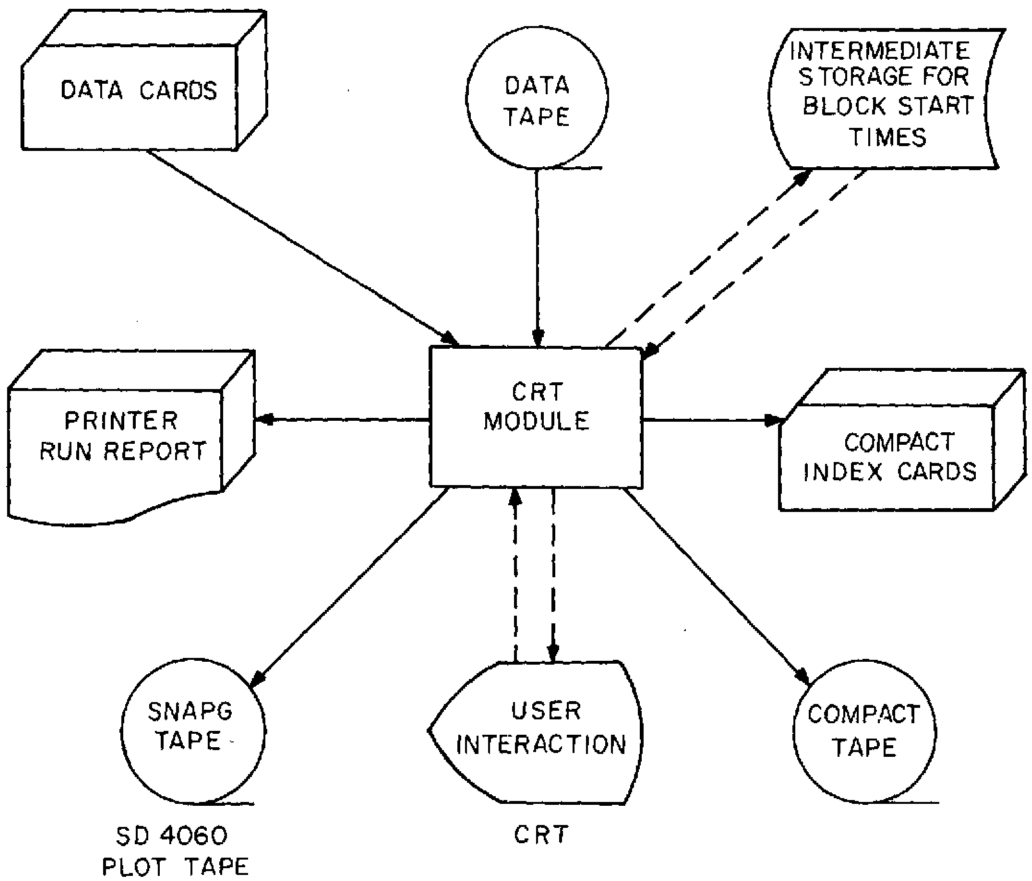


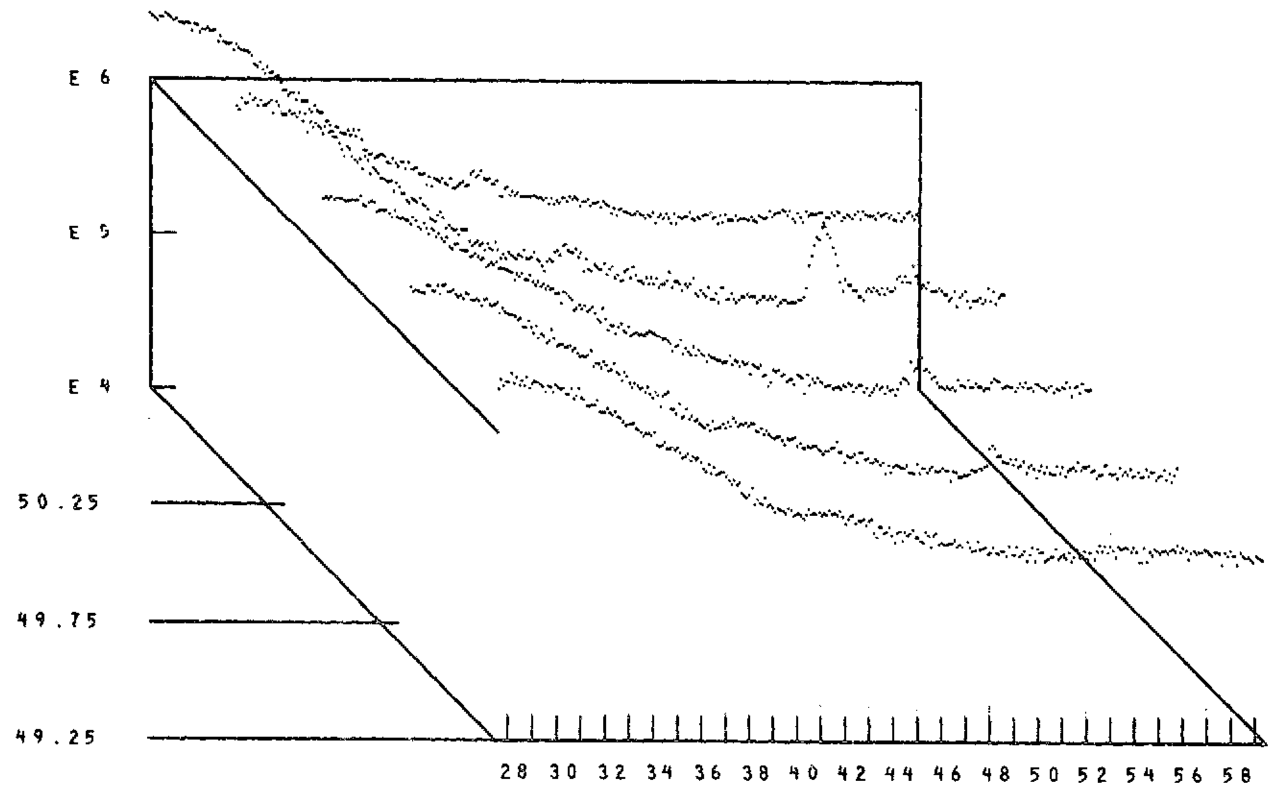
Figure 5

2250 HARDCOPY

C L A R K L A K E S O L A R S P E C T R O G R A P H

CURVE FREQUENCIES

2	49.25
6	49.65
9	49.95
13	50.35
17	50.75



BLOCK START 71.10.20.17.13.27.488

BLOCK NO. = 5

LOW RANGE

+ANTENNAE

Figure 6

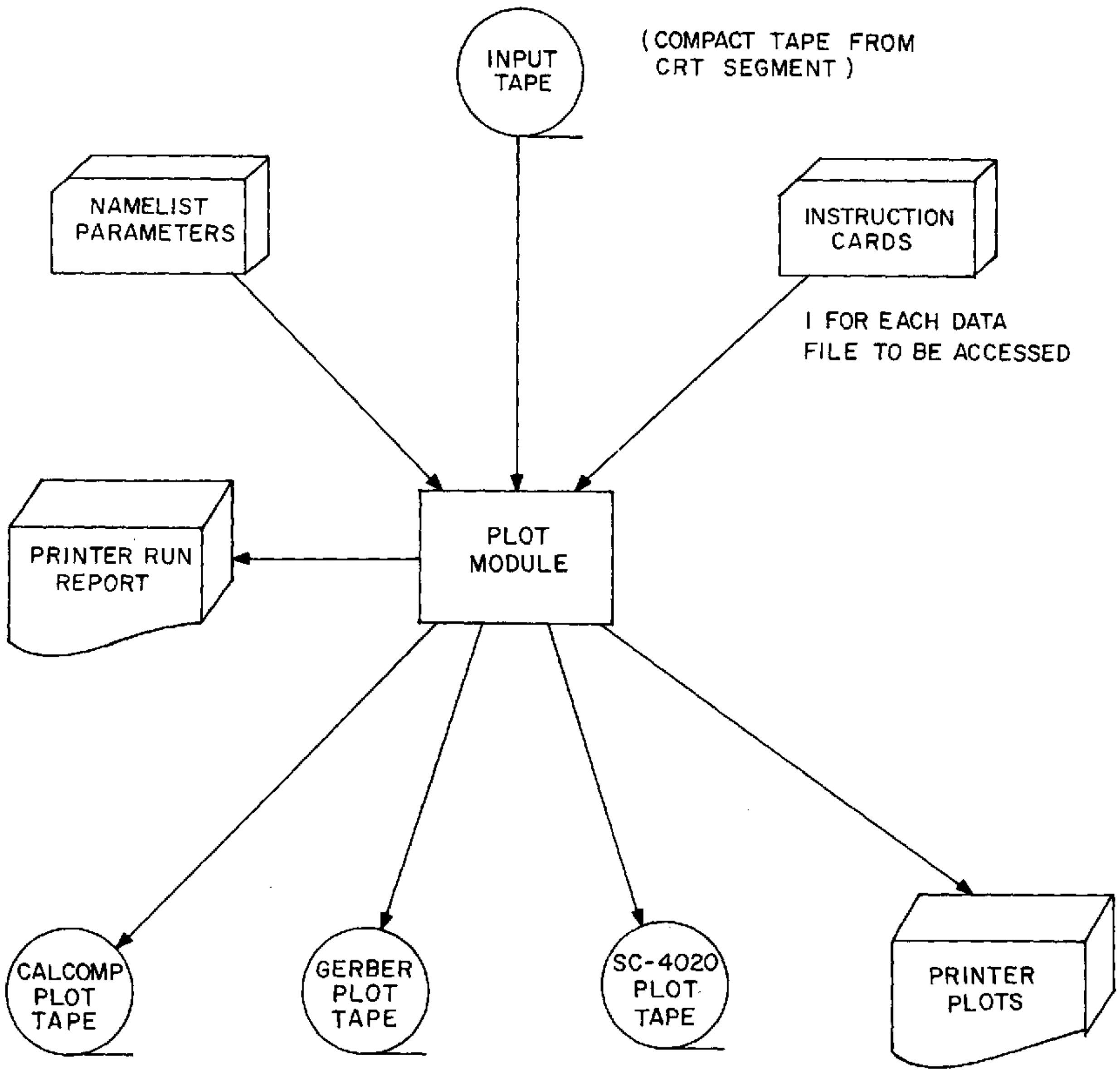
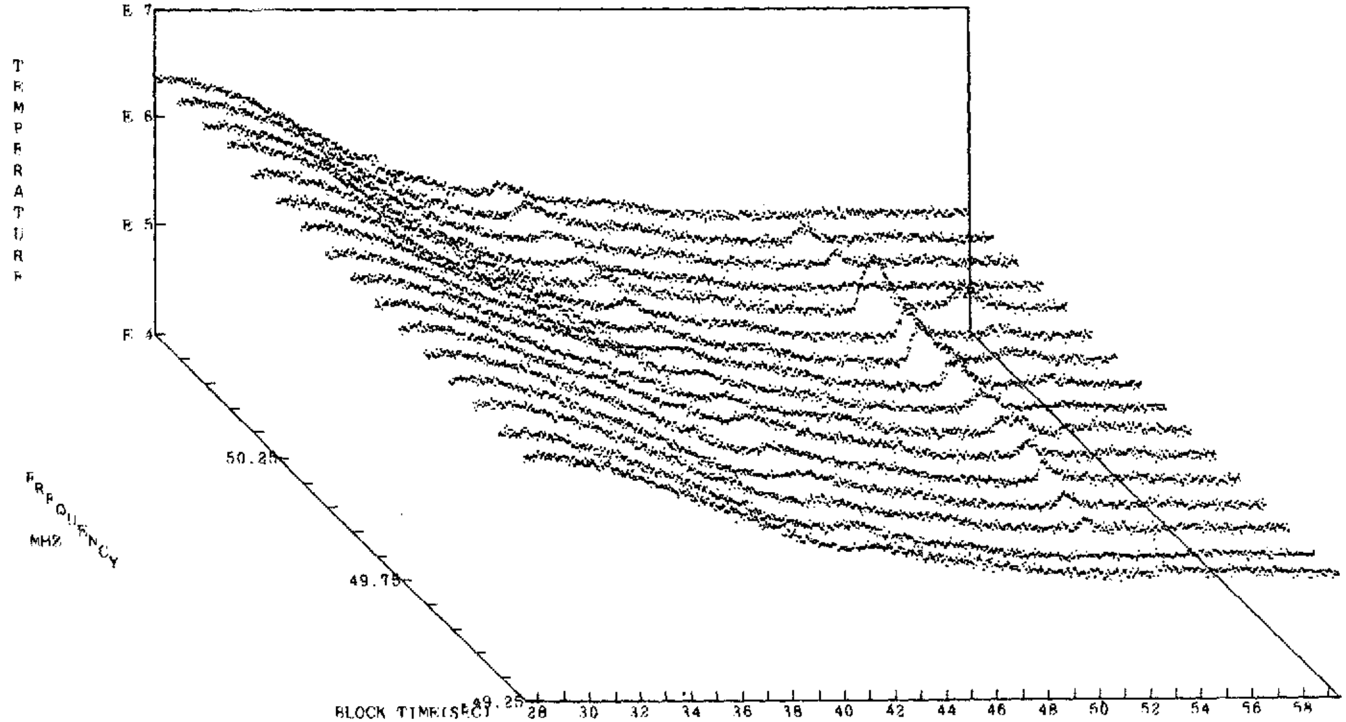

INPUT TAPE
(COMPACT TAPE FROM CRT SEGMENT)
NAMELIST PARAMETERS
INSTRUCTION CARDS
1 FOR EACH DATA FILE TO BE ACCESSED
PRINTER RUN REPORT
PLOT MODULE
CALCOMP PLOT TAPE
GERBER PLOT TAPE
SC-4020 PLOT TAPE
PRINTER PLOTS

Figure 7

CLARK LAKE SOLAR SPECTROGRAPH
LOW RANGE

CH	FREQ	CH	FREQ	CH	FREQ	CH	FREQ
2	49.25	6	49.65	10	50.05	14	50.45
3	49.35	7	49.75	11	50.15	15	50.55
4	49.45	8	49.85	12	50.25	16	50.65
5	49.55	9	49.95	13	50.35	17	50.75

ANTENNAE COUNT= 1



BLOCK START=71.10.20.17.13.27.488
BLOCK LENGTH 31983
INPUT TAPE= 1RA1091
PLOT TAPE= 1TD7417
CENTER FREQUENCY= 50.00

PROCESSING DATE= 73 01 26 05 21 19
BLOCK NO.= 4
FRAME NO. 10

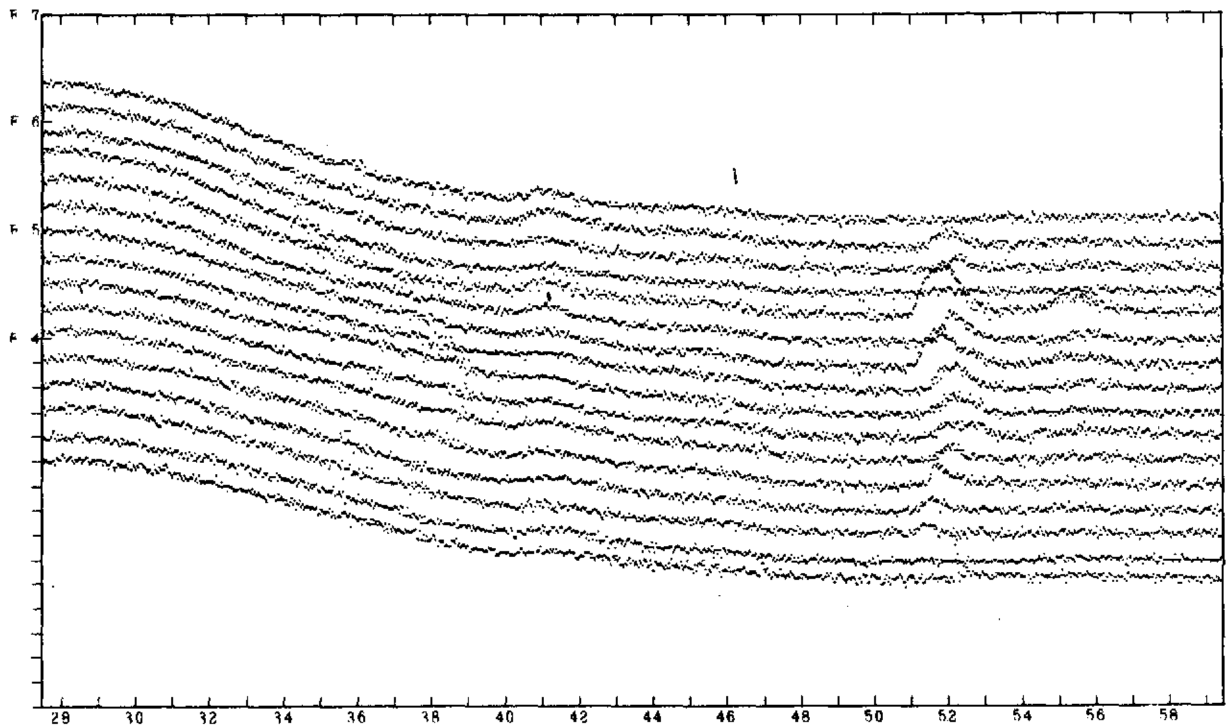
Figure 8

CLARK LAKE SOLAR SPECTROGRAPH

LOW RANGE

CH	FREQ	CH	FREQ	CH	FREQ	CH	FREQ
2	49.25	6	49.65	10	50.05	14	50.45
3	49.35	7	49.75	11	50.15	15	50.55
4	49.45	8	49.85	12	50.25	16	50.65
5	49.55	9	49.95	13	50.35	17	50.75

ANTENNAE COUNT= 1



BLOCK START=71.10.20.17.13.27.488
BLOCK LENGTH 31983
INPUT TAPE= 1RA1091
PLOT TAPE= 1TD7417
CENTER FREQUENCY= 50.00

PROCESSING DATE= 73 01 26 05 21 19
BLOCK NO.= 4
FRAME NO. 11

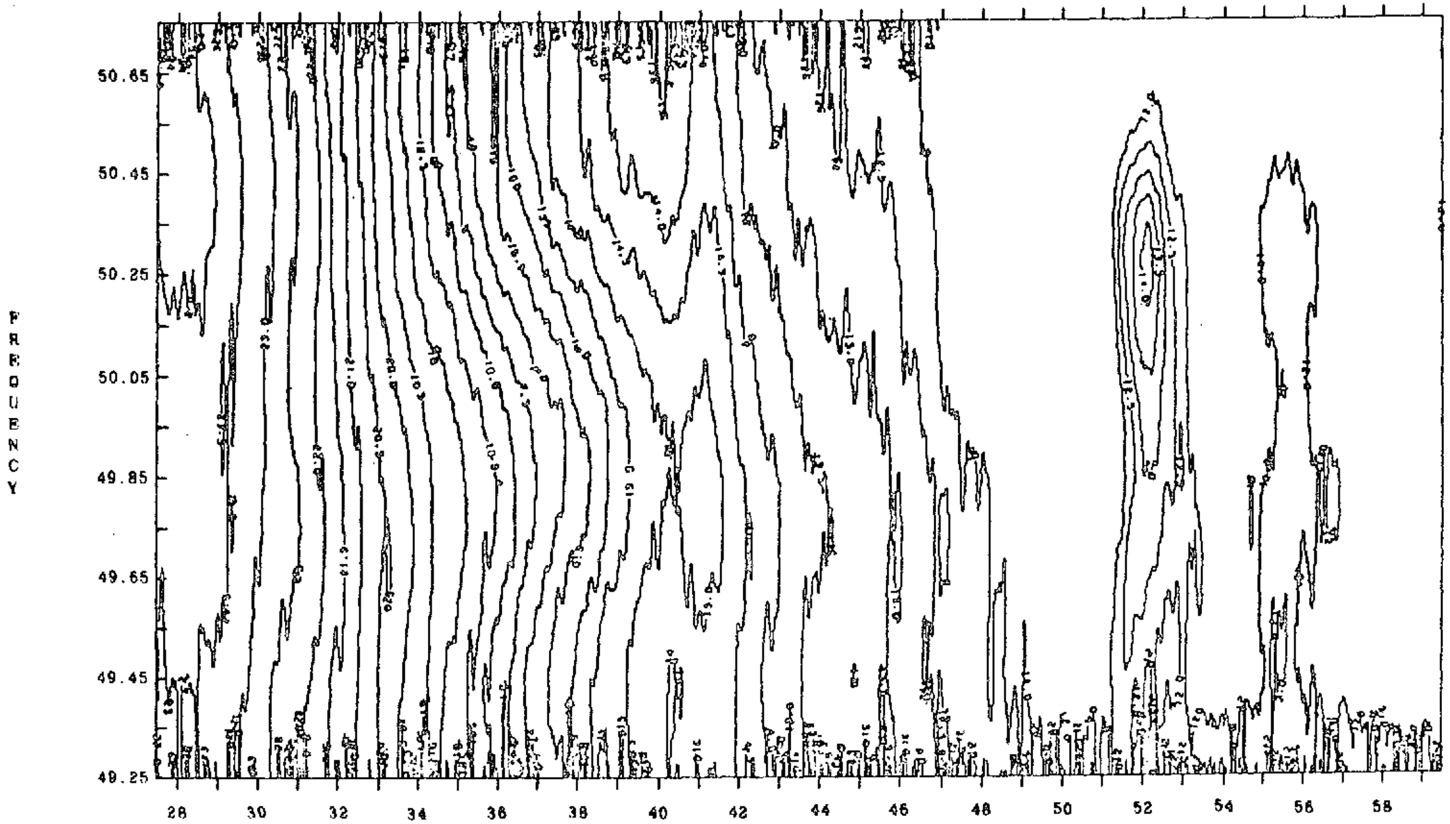
Figure 9

CLARK LAKE SOLAR SPECTROGRAPH
LOW RANGE

CH	FREQ	CH	FREQ	CH	FREQ	CH	FREQ
2	49.25	6	49.65	10	50.05	14	50.45
3	49.35	7	49.75	11	50.15	15	50.55
4	49.45	8	49.85	12	50.25	16	50.65
5	49.55	9	49.95	13	50.35	17	50.75

CONTOUR INTERVAL= 0.50
SMOOTHING FACTOR= 0.20
TIMES SMOOTHED = 3
FIRST CONTOUR= 12.00
LAST CONTOUR= 0.00

ANTENNAE COUNT= 1
ANTENNA = 0



BLOCK START=71.10.20.17.13.27.488
BLOCK LENGTH 31963
INPUT TAPE= 1RA1091
PLOT TAPE= 1TD7417
CENTER FREQUENCY= 50.00

PROCESSING DATE= 73 01 26 05 21 19
BLOCK NO.= 4
FRAME NO. 12

Figure 10